Cartilage assessment in femoroacetabular impingement using Bloch-simulation-based T2 mapping at 3 T: preliminary validation against intra-operative findings

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Introduction Femoroacetabular impingement (**FAI**) has been recognized as one of the causes of hip osteoarthritis[1] with surgery being frequently advocated for preventing its development. However, these procedures are only successful in patients with limited damage of articular cartilage[2]. T_2 mapping can detect early changes in cartilage collagen structure and water content[3], but it is challenging to perform in vivo. In fact, conventional single spin-echo (**SSE**) protocols are impractical due to extensive scan times, whereas faster multi spin-echo (**MSE**) sequences are strongly biased by stimulated and indirect echoes, non-rectangular slice profiles, and inhomogeneous transmit ($\mathbf{B_1^+}$) field distribution. Moreover, the deviation of MSE signal from a theoretical exponential decay $S(t)=S_0\exp[-t/T_2]$ will dependent on the protocol implementation and parameter-set, causing T_2 values of the same subject to vary between scanners and vendors[4,5] and preventing adoption of quantitative T_2 as a biomarker for cartilage damage across patient populations. We recently introduced a new method – the EMC algorithm[6] – which overcomes these limitations and can deliver accurate and reliable maps of the true tissue T_2 values in a fashion that is independent of the scan settings[7]. In this work we hypothesize that T_2 values reconstructed with the EMC technique improve detection of hip cartilage lesions, using surgical findings as the reference.

Methods EMC algorithm: Bloch simulations of the prospective MSE protocol were performed using the exact RF pulse shapes and other experimental parameters. Simulations were repeated for a range of T_2 and B_1^+ values (T_2=1…1000ms, B_1^+ = 50…130 % of nominal value), producing a database of EMCs, each associated with a unique [B_1^+,T_2] value pair. Data acquisition: retrospective review of 18 hips (10 left) was performed in 17 patients (6 males) diagnosed with FAI and either torn or detached labrum. Patients (38 ± 12 y/o) underwent pre-operative MRI on 3 T MRI scanners (Siement Verio and Skyra). Prior to scan, following a screening for the risk of Nephrogenic Systemic Fibrosis (NSF), patients received an intravenous injection of a double dose (0.2 mmol/kg) of Gd-DTPA^{2-} for indirect arthrography. MSE data was acquired for a radial section depicting the anterior-superior region of the hip articular cartilage (**AC**). Imaging parameters: {TR=3000 ms, echo-spacing=12 ms, resolution=0.6x0.6 mm^2, slice=4 mm, N_{echoes}=7, bandwidth=454 (Verio) and 225 (Skyra) Hz/px, T_{acq}≈6 min using 2x GRAPPA acceleration}. Each patient underwent arthroscopy 53 ± 34 days after the MRI to correct the bone defect associated with FAI. Reconstruction: T_2 maps were generated using (***1***) standard monoexponential fit and (***2***) the EMC algorithm[6] by pixel-by-pixel matching the time-series of MSE DICOMs to the EMC database via l_2-norm minimization of the difference between experimental and pre-calculated EMCs. Statistical analysis: Two regions of interest (**ROIs**) were segmented on the images (Figure 1). ROI1: the weight-bearing portion of the cartilage (femoral & acetabular combined); ROI2: the AC near the chondrolabral junction, where cartilage lesions are normally found in FAI. Patient population was divided into lesion (any kind of chondral defect) and non-lesion subgroups based on surgical findings. Mean and standard-deviation (**SD**) were calculated for both ROIs and a normalized T_2– norm index was defined as the ratio ROI2/ROI1 in order to remove inter-patient baseline variability.

Results Figure 2 shows the T_2 value in ROI1 for each of the 18 patients. The two graphs reflect the lower inter-subject variability associated with the EMC algorithm, as well as the non-uniform bias toward higher T_2 values of the exponential fit. Average standard-deviation reduced in this case from 8.3 to 6.8 ms when using the EMC approach. An increased statistical difference between the two groups [Lesion; non-Lesion] was gained when using the EMC *vs.* Exponential fit, with corresponding T_2-norm indices of [1.03 ± 0.22, 0.84 ± 0.13] *vs.* [1.01 ± 0.17; 0.87 ± 0.14] and P-values of 0.0036 *vs.* 0.080 (where lower P-values reflecting higher statistical confidence).

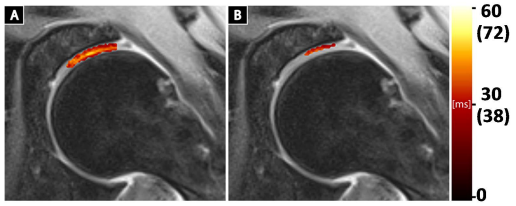

Figure 1: T_2 values in the articular cartilage superimposed on a PD-weighted MR image for a representative hip. The average T_2 in a region of interest (B) associated, with an arthroscopically proven cartilage lesion (i.e., chondral delamination in this case), was normalized by the average T_2 in the anterior-superior region of the cartilage (A). Colorbar shows T_2 values calculated using both EMC algorithm and exponential fit (in parentheses).

Discussion Quantitative assessment of T_2 values in the hip articular cartilage is particularly challenging owing to several factors, including the need to differentiate thin cartilage layers, magic angle effects, fast-relaxing T_2 components, and partial volume artifacts between acetabular and femoral layers. These same limitations also impair the accuracy of pre-operative radiologic evaluation. Several advanced T_2 mapping techniques have recently emerged[8,9], showing promise for quantitative evaluation of cartilage damage. In this study we have shown that the EMC approach is able to improve the detection of cartilage lesions and reduce intra-subject variability – consistently, for each and every patient. This was achieved despite the potential mismatch between the MRI data-segmentation and the radiologic and surgical reports, with respect to exact lesion location. We expect these statistics to become more significant as additional data is collected. We believe that the higher accuracy and validated stability[6] of the EMC algorithm can improve the correlation with symptoms and enable longitudinal and cross-platform, multi-center clinical studies.

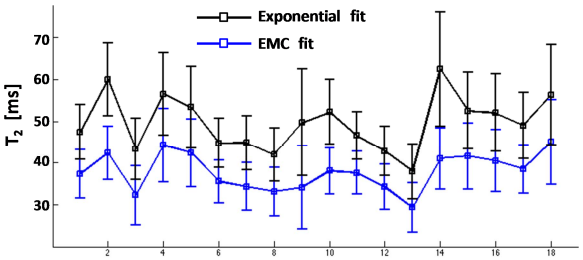

Figure 2: T_2 mean and SD for 18 FAI patients

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